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IMPROVED SENSING ELEMENT
ARRANGEMENT FOR A FINGERPRINT SENSOR

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PATENT

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**IMPROVED SENSING ELEMENT
ARRANGEMENT FOR A FINGERPRINT SENSOR**

BACKGROUND OF THE INVENTION

[0001] The present invention relates generally to capacitive fingerprint sensors, and more particularly to improvements in the structure of sensing elements that capacitively interact with the fingerprint-bearing skin of a user's finger.

[0002] A capacitive distance sensor is disclosed in commonly-assigned U.S. Patent No. 6,114,862 by *Tartagni et al.*, the disclosure of which is hereby incorporated by reference. The *Tartagni et al.* patent discloses the basic structure and operation of a conventional solid-state fingerprint sensor that is formed on a single semiconductor chip. FIGS. 1 and 2 herein correspond to FIGS. 1 and 4 of the *Tartagni et al.* patent, and are briefly described below to facilitate an understanding of the application of the present invention in the context of a two-dimensional fingerprint sensor array.

[0003] The present invention provides an improvement in the capacitive sensing element that is replicated in each of the sensor cells or “pixels” that are included in a two-dimensional array of sensor cells. Several embodiments of the improved sensing element are described.

SUMMARY OF THE INVENTION

[0004] An improved sensing element for a capacitive fingerprint sensor includes capacitor plates at multiple levels separated by dielectric material, the plates including a surface plate disposed on a top surface of a composite dielectric body, and spaced first and second plates disposed beneath the surface plate and separated therefrom by portions of the composite dielectric body. The surface plate and the adjacent top surface portions of the composite dielectric body define a sensing surface to which the fingerprint-bearing skin of a user’s finger is applied during a sensing operation. The surface plate and proximate skin, which may be either a fingerprint ridge or valley, together define a fingerprint capacitor. The surface plate and underlying first and second plates define respective first and second capacitors. These two capacitors are interconnected with active circuit elements that generate a pixel output signal, which is a function of the variable capacitance of the fingerprint capacitor.

BRIEF DESCRIPTION OF THE DRAWINGS

[0005] FIG. 1 is a block diagram of a prior art fingerprint sensor over which the present invention provides an improvement;

[0006] FIG. 2 is an enlarged schematic cross section of a small portion of a finger positioned above two adjacent sensor cells of the device of FIG. 1;

[0007] FIG. 3 is an enlarged schematic cross section of a small portion of a finger positioned above a sensor cell, showing capacitor plates in cross section and capacitor symbols superimposed thereon to facilitate an understanding of the functionality of the structural elements in accordance with the invention;

[0008] FIG. 4 is an enlarged schematic cross section similar to FIG. 3 showing an alternative circuit arrangement of elements in accordance with the invention;

[0009] FIG. 5 is a circuit diagram of the capacitors that make up a basic sensing element according to the invention;

[0010] FIG. 6 is a generalized depiction of the sensing element of FIG. 5 showing its nodes that connect with other circuit elements;

[0011] FIG. 7 is a circuit diagram corresponding to FIG. 3 showing one of two alternative circuits according to the invention;

[0012] FIG. 8 is a circuit diagram similar to FIG. 7 and corresponding to FIG. 4 showing the other of two alternative circuits;

[0013] FIGS. 9-12 are schematic cross sections of alternative embodiments of sensing elements according to the invention, showing a surface capacitor plate and capacitor plates embedded therebelow in dielectric material;

[0014] FIG. 10A is an alternate view of the structure of FIG. 10 showing electrical circuit elements overlaid on the cross-sectional plate structure; and

[0015] FIG. 10B is a plan view of an interdigitated layout of the embedded capacitor plates of FIG. 10A.

DESCRIPTION OF THE PRIOR ART

[0016] FIG. 1 shows a layout for prior art sensor device 1 for sensing a distance between a sensing surface of the device and the fingerprint-bearing skin of a user's finger. The sensor device 1 includes a number of cells 2 arranged to form an array 3, each cell constituting an elementary sensor or pixel. The simplicity of the individual cells 2 enables the sensor device 1 to be implemented in integrated form on a single semiconductor chip.

[0017] The sensor device 1 also comprises a horizontal scanning stage 5 and a vertical scanning stage 6 for enabling one of the cells 2 at a time according to a predetermined scanning pattern. The stages 5 and 6 enable the outputs of the cells to be read using shift registers, address decoders, or other suitable circuitry.

[0018] The sensor device 1 also comprises a supply and logic unit 7, which supplies the circuit elements of the device with power (including the cells 2), feeds the necessary reference voltages, and controls the timing of device operations. FIG. 1 shows that the supply and logic unit 7 includes a voltage source 12. A buffer 8 is interconnected with the outputs of all the cells 2, and includes an output 10 for sequentially generating signals corresponding to the outputs of the cells 2 according to the sequence in which they are enabled by scanning the stages 5, 6.

[0019] FIG. 2 shows the details of two adjacent cells 2A and 2B with a skin surface portion 18 of a human finger positioned thereover. The elements of each of these two cells bear the designators A or B but are essentially identical, as will now be described. Each cell 2 preferably comprises a low-power inverting amplifier 13 having an input node 16 and an output node 17, which also defines the output of individual cell 2. Each cell 2 also preferably includes first and second coplanar capacitor plates 23 and 24, positioned facing the skin surface 18 of the finger being printed. The plates 23, 24 are covered with a dielectric layer 25 having a sensing

surface 26 that covers the face of the integrated sensor device 1, including the entire array 3 of cells 2. A reset switch 19 is connected between the input node 16 and output node 17 of the inverting amplifier 13. An input capacitor 20 is connected between an input node 21 of the cell 2 and the input node 16 of the inverting amplifier 13. The input node 16 of the inverting amplifier 13 also has a parasitic capacitance depicted by capacitor 30. Likewise, the output node 17 has a parasitic capacitance depicted by capacitor 31.

[0020] The skin surface 18 includes a ridge 39 contacting the sensing surface 26 adjacent to the first cell 2A and a valley 38 disposed just above the sensing surface 26 adjacent to the second cell 2B. As a result, the first and second cells 2A, 2B will each produce different capacitive coupling responses in the sensor device 1. Accordingly, the first cell 2A will sense a smaller distance d_1 , signifying the ridge 39, than the second cell 2B, which senses a larger distance d_2 , signifying the valley 38. The distance d_2 sensed by the second cell 2B will be the average of a distance d_{2a} between the first capacitor plate 23B and the portion of the skin surface 18 directly above the first capacitor plate 23B and a distance d_{2b} between the second capacitor plate 24B and the portion of the skin surface 18 directly above the second capacitor plate 24B. From a lumped-model point of view, this structure realizes a three-capacitor scheme that can sense the difference between a contacting member, a ridge, and a non-contacting member, a valley.

DETAILED DESCRIPTION OF THE INVENTION

[0021] The present invention will now be described with reference to FIGS. 3-12, like elements in the various figures being designated by the same reference characters.

[0022] Referring to FIG. 3, one embodiment of a sensor cell or pixel is shown and designated generally by reference numeral 40. Each pixel 40 is typically one of many identical such pixels arranged in a two-dimensional array formed on a semiconductor chip that is the essential component of a solid-state fingerprint sensing device. Pixel 40 has an input node 42 and output node 44. The input node 42 receives a pulsed input signal ΔV from a reference voltage source V_r during a read operation. The ΔV input signal preferably is applied to all pixels in a selected column of the pixel array. For example, FIG. 1 shows vertical scanning stage 6 that selects individual columns of the array 3, one column at a time. In FIG. 3, the output node 44 is connected to output circuitry 48 that senses output signals from the pixel 40 periodically.

[0023] The output of pixel 40 is generated by an inverting amplifier A such as that described in U.S. Patent No. 6,114,862. The inverting amplifier A has an input node 50 corresponding to its negative (-) input, and an output node corresponding to the pixel's output node 44. An input capacitor C_{input} interconnects the pixel's input node 42 with the inverting amplifier's input node 50. The inverting amplifier's positive (+) input is connected to a voltage source, such as ground. The ground symbols in the figures may represent the actual ground terminal of the fingerprint sensing device or may represent a virtual ground bus internal to the chip. A parasitic capacitor C_{pi} connects the inverting amplifier's input node 50 to ground, and a parasitic capacitor C_{po} connects the output node 44 to ground. Just prior to a sensing operation, a reset switch 56 is opened to prepare the inverting amplifier A to generate an accurate output signal during the sensing operation. The reset switch 56 may be a

conventional transistor, such as an NMOS transistor, and interconnects the inverting amplifier's input node 50 and output node 44.

[0024] The active elements just described (i.e., transistor 56 and the inverting amplifier A) are formed in part in a semiconductor substrate 58, which conventionally will have an upper epitaxial layer with isolated active areas formed therein. It will be appreciated that the pixel 40 is a small part of a larger fingerprint sensor that is fabricated as a specialized semiconductor integrated circuit chip. The starting material is typically a monocrystalline silicon wafer large enough to include many identical fingerprint sensors that are eventually separated by slicing the wafer into chips. The individual chip substrate 58 has a composite dielectric body 60 disposed thereon and defining a sensing surface 62 in the finished device. A dashed line 64 schematically indicates a transition from the composite dielectric body 60 to the substrate 58 below.

[0025] The composite dielectric body 60 includes multiple layers of dielectric or insulating material that are not shown separately. These dielectric layers may include conventional oxide and nitride layers known to those skilled in the art of semiconductor device fabrication. Within the dielectric body 60 are several levels of conductive layers that are deposited and patterned into separate conductors. Three such conductors are shown in FIG. 3 as part of pixel 40 and are labeled: Surface Plate, Plate A and Plate B. The upper surface of the Surface Plate is flat and is preferably coplanar with surrounding flat surface portions of the dielectric body 60, together defining part of the sensing surface 62. Plate A and Plate B are embedded in the dielectric body 60 beneath the Surface Plate. Known photolithographic patterning techniques may be used to form the plates and various suitable conductive materials may be used. For example, the Surface Plate may consist essentially of tungsten and Plates A and B may consist essentially of aluminum. Similarly-formed plates 66 and 68 of an adjacent pixel are partially shown at the broken-off right edge of the dielectric layer 60.

[0026] The Surface Plate is shown contacting a portion of a user's finger 70, which includes fingerprint-bearing skin 72 having a typical fingerprint ridge 74 and fingerprint valley 76. The portion of the skin 72 proximate to the Surface Plate defines a capacitor C_f whose capacitance varies with the proximity of the skin to the Surface Plate. The capacitance of Capacitor C_f is largest when a fingerprint ridge is in contact with the Surface Plate, and is smallest when a fingerprint valley is directly over the Surface Plate.

[0027] Plate A and the portion of the Surface Plate juxtaposed thereabove define a first coupling capacitor C_a , and Plate B and the portion of the Surface Plate juxtaposed thereabove define a second coupling capacitor C_b . A capacitor C_p represents the parasitic capacitance between the Surface Plate and ground. Plate A is connected to the inverting amplifier's input node 50, and Plate B is connected to the inverting amplifier's output node 44.

[0028] It will be understood that the circuit elements designated C_f , C_a and C_b in FIG. 3 merely show how the finger 70, the Surface Plate, Plate A and Plate B interact electrically; they are not separate structural elements like the plates themselves. Likewise, capacitor C_p in FIG. 3 is parasitic and not a separate structural element. However, capacitor C_{input} is a separate structural element designed to have a particular capacitance value within manufacturing tolerances. Capacitor C_{input} may be formed in any suitable manner, and may comprise, for example, metal plates at two different levels, or a metal plate disposed over a conductive polysilicon layer, or a conductive polysilicon layer disposed over a heavily-doped surface region in the substrate 58.

[0029] The capacitance values of capacitors C_a and C_b should be as large as practical to ensure good coupling of the variable capacitance of capacitor C_f across the inverting amplifier A. The space separating the Surface Plate from Plates A and B

may be a conventional dielectric material such as silicon nitride or silicon dioxide. Techniques for fabricating such layers are well known in the art. The dielectric material separating the Surface Plate from Plate A and Plate B should be less than 1.0 micron thick, preferably having a thickness of about 0.2 to 0.3 microns.

[0030] The transistor elements of the device, including transistor 56 and the transistors that comprise the inverting amplifier A, are formed at the upper surface of the substrate, and typically include polysilicon gate electrodes disposed within the composite dielectric body 60 just above the substrate 58. Because these conventional transistor elements are well known, their structures are not specifically illustrated but are schematically depicted by the circuit diagram superimposed on the cross-sectional face of the substrate 58. It should also be understood that the parasitic capacitances C_{pi} and C_{po} arise from structures that exist in both the substrate 58 and in the dielectric body 60.

[0031] When a particular pixel is read, a pulse ΔV is generated by reference voltage source V_r . This pulse is applied to the pixel 40 through the pixel input node 42. The pulse ΔV propagates through capacitor C_{input} and appears at the input node 50 of the inverting amplifier A. Prior to reading the pixel 40, switch 56 is opened. The inverting amplifier A generates an output signal at its output node 44, which is communicated to the output circuitry 48. The output circuitry digitizes the pixel output signal on node 44 for communication off the chip together with other pixel outputs in sequence for further processing. The analog value of the output signal on output node 44 is determined by the gain of the inverting amplifier A, which is a function of the capacitance in its feedback loop. The series-connected capacitors C_a and C_b define the feedback loop and their combined value is modulated by the capacitance of the fingerprint capacitor C_f .

[0032] An alternative circuit arrangement is shown in FIG. 4, the pixel depicted therein being designated by reference numeral 80 to distinguish it from the pixel 40

of FIG. 3. However, like elements are designated by the same reference characters. It will be noted that pixel 80 of FIG. 4 has Plate A connected to the pixel input node 42, and Plate B connected to the input node 50 of the inverting amplifier A. The input capacitor C_{input} of FIG. 3 is eliminated. In the circuit of pixel 80 in FIG. 4, a feedback capacitor C_{fb} is connected across the inverting amplifier's input node 50 and output node 44. The feedback capacitor C_{fb} is designed to have a particular capacitance value within manufacturing tolerances, which affects the gain of inverting amplifier A and causes it to function as a charge integrator. The feedback capacitor C_{fb} may be formed in any suitable manner, and may comprise, for example, metal plates at two different levels, or a metal plate disposed over a conductive polysilicon layer, or a conductive polysilicon layer disposed over a heavily-doped surface region in substrate 58.

[0033] In the alternative arrangements of FIGS. 3 and 4, the respective pixels 40 and 80 each have sensing elements defined by four capacitors: C_a , C_b , C_f and C_p . These four capacitors are shown generalized in the FIG. 5 with connecting nodes: A, B, F, and ground. Nodes A and B correspond to Plates A and B in FIGS. 3 and 4. FIG. 5 also shows that capacitors C_a and C_b share a common node 82, which corresponds to the Surface Plate. Node F corresponds to the fingerprint-bearing skin 72, which defines the variable fingerprint capacitor C_f with the Surface Plate. Parasitic capacitor C_p is connected between node 82 and ground.

[0034] FIG. 6 further generalizes the arrangement of the Surface Plate and Plates A and B and the capacitors they define. By comparison with FIG. 5, FIG. 6 depicts a generalized Sensing Element corresponding to capacitors C_a , C_b , C_f and C_p showing only the connecting nodes: A, B, F, and ground.

[0035] FIG. 7 is a simplified circuit diagram corresponding to the pixel 40 of FIG. 3, and FIG. 8 is a simplified circuit diagram corresponding to the pixel 80 of FIG. 4, both figures using the generalized Sensing Element of FIG. 6, designated SE. FIGS.

7 and 8 show alternative circuit applications for the Sensing Element embodiments of the present invention. In FIG. 7 the Sensing Element SE is connected in the feedback loop of the inverting amplifier A, whereas in FIG. 8 the Sensing Element SE is in the input path between the pixel's input node 42 and the inverting amplifier's input node 50. Various embodiments of the inventive Sensing Element of the present invention will now be described in conjunction with FIGS. 9-12.

[0036] Referring to FIG. 9, a basic form of the Sensing Element useful in either pixel 40 or 80 is shown in schematic cross section. Only the upper dielectric portion 60 of the pixel is shown. The substrate (not shown) will be understood to be below the dashed line 64. In this embodiment, it is important for the dielectric material 84 separating the Surface Plate from Plates A and B therebelow to have a minimum practical thickness. Preferably, the separating dielectric 84 should be about 0.2 to 0.3 microns thick. A minimum practical thickness for the separating dielectric 84 maximizes the capacitive coupling between the Surface Plate and Plates A and B therebelow.

[0037] Referring to FIG. 10, an alternative embodiment of the inventive Sensing Element is shown in which an additional Plate C has been laterally interposed between Plates A and B. Plate C is connected to the Surface Plate by a conductor 86, such as a metal via. This permits use of a much thicker dielectric body portion 88 separating the Surface Plate from the plates therebelow. For example, dielectric body portion 88 can be greater than ten microns thick and preferably is from 15 to 20 microns thick. Plates A, B and C are coplanar and have dielectric spacers 90 and 92 separating the edges of Plate C from the respective opposed edges of Plates A and B, as shown. Plates A, B and C can be etched from the same conductive layer, such as an aluminum metalization, cutting 1.0 micron gaps therein to define the separate plates. Thus, the capacitors C_a and C_b of FIG. 5 are formed between the facing edges of the embedded Plates A, B and C. This effect is illustrated more clearly by FIG. 10A.

[0038] In FIG. 10A, a capacitor C_{a1} is formed between Plate A and Plate C, and a capacitor C_{a2} is formed between Plate A and the Surface Plate. If the thickness of the dielectric material separating the Surface Plate from Plate A (preferably from 15 to 20 microns) is very much greater than the thickness of the dielectric material separating Plate A from Plate C (preferably 1.0 micron), capacitor C_{a1} can be made larger than capacitor C_{a2} . Similarly, capacitor C_{b1} formed between Plate B and Plate C can be made larger than capacitor C_{a2} . It will be appreciated that the layouts of the Surface Plate and embedded Plates A, B and C can be designed to insure that capacitors C_{a2} and C_{b2} are negligible relative to capacitors C_{a1} and C_{b1} . One such layout is depicted in FIG. 10B.

[0039] FIG. 10B shows an interdigitated arrangement for Plates A, B and C of FIG. 10A. Plates A and B have inwardly extending fingers 94 and Plate C has outwardly extending fingers 96, as the plan view layout of FIG. 10B shows. The multiple interdigitated fingers 94 and 96 form the facing edges that define the capacitors C_{a1} and C_{b1} of FIG. 10A. Such an interdigitated arrangement greatly increases the capacitance of capacitors C_{a1} and C_{b1} , since the shared area of the respective capacitor plates is dramatically increased.

[0040] The layout of FIG. 10B is just one of many possible alternatives that can increase the capacitance between adjacent plates within the limits of a pixel's dimensions. For example, FIG. 8 of *Tartagni et al.* U.S. Patent No. 6,114,862 shows a C-shaped plate and a complementary adjacent plate arrangement that can be converted into three adjacent plates by replicating a mirror-image layout of the two adjacent plates. The result is easily envisioned as a C-shaped plate on the left, a mirror-imaged C-shaped plate on the right, and a center plate therebetween, the center plate having a common bar-shaped portion in the middle and extensions through the C-shaped gaps to adjoining dumbbell-shaped ends within the C-shaped plates. The extensions and dumbbell-shaped ends are like two oppositely oriented

fingers 96 of the interdigitated layout of FIG. 10B and serve the same capacitive enhancing function in a similar way.

[0041] Referring again to FIGS. 9 and 10, it will be appreciated that the plate arrangement of FIG. 10 permits use of a very thick dielectric portion 88 separating the Surface Plate from the lower embedded plates compared to the relatively thin separating dielectric portion 84 required by the arrangement of FIG. 9. This is made possible by including Plate C in the arrangement of FIG. 10 and interconnecting it with the Surface Plate using conductor 86. Note also that the Surface Plate need not be juxtaposed directly over Plates A and B. The formation of capacitors C_a and C_b using embedded Plate C connected to the Surface Plate allows one to decouple the layout geometry of the Surface Plate from the embedded plates therebelow. This is also true of the structures of FIGS. 11 and 12. The thick dielectric portion 88 may be a hard glass material that can be deposited using conventional CVD techniques. Also, a thin silicon nitride or oxynitride layer can be used atop a thicker glass layer, which together can form the thick dielectric portion 88.

[0042] FIGS. 11 and 12 show additional embodiments of the inventive Sensing Element using different arrangements of lower embedded plates. These two arrangements use three levels of conductors. The embedded lower level plates in FIGS. 11 and 12 can consist essentially of aluminum or can comprise other suitable conductive materials.

[0043] In FIG. 11, Plate C is included beneath Plates A and B. Plate C is connected to the Surface Plate by conductor 86. The dielectric material portion 88 separating the Surface Plate from the underlying Plates A and B can be relatively thick, while a relatively thin dielectric material portion or layer 98 separates Plate C from Plates A and B. Therefore, capacitors C_a and C_b of FIG. 5 are effectively formed between Plate C and Plates A and B, respectively.

[0044] FIG. 12 shows an arrangement similar to FIG. 11 with Plate C in this case located in the second level and Plates A and B located in the third level of conductive plates. Again, Plate C is connected to the Surface Plate by conductor 86 so that the dielectric material 88 can be made very thick while the dielectric material 98 is made relatively thin. In FIGS. 11 and 12, dielectric material 98 should be less than 1.0 micron thick and preferably is from 0.2 to 0.3 micron thick, whereas dielectric material 88 should be greater than 10.0 microns thick and preferably is from 15 to 20 microns thick.

[0045] It will be appreciated that various additional sensor element structures can be envisioned from the foregoing description. Features from FIGS. 10-12 can be combined to further improve capacitive coupling, or to facilitate layout-related or process-related design requirements. For example, Plate C in FIGS. 11 or 12 can include an additional common plate lying coplanar with Plates A and B and interposed therebetween in the manner of Plate C of FIG. 10.

[0046] Moreover, other materials than those described herein can be employed. For example, the Surface Plate can be formed from a titanium oxide film rather than tungsten. Additionally, composite conductive layers can be used. For example, in the structure of FIG. 12, Plate C can be formed by a layer of titanium oxide atop a layer of aluminum, and Plates A and B can be aluminum or can be formed from a conventional conductive polysilicon layer, such as silicided polysilicon.

[0047] Although preferred embodiments have been described in detail, it should be understood that various changes, substitutions and alterations can be made therein without departing from the spirit and scope of the invention as defined by the appended claims.